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Ozawa et al.(10) **Pub. No.: US 2006/0028272 A1**(43) **Pub. Date: Feb. 9, 2006**(54) **CLASS D AMPLIFIER**(52) **U.S. Cl. 330/251**(75) Inventors: **Akio Ozawa**, Saitama-ken (JP);
Kazuyuki Kudo, Saitama-ken (JP)(57) **ABSTRACT**

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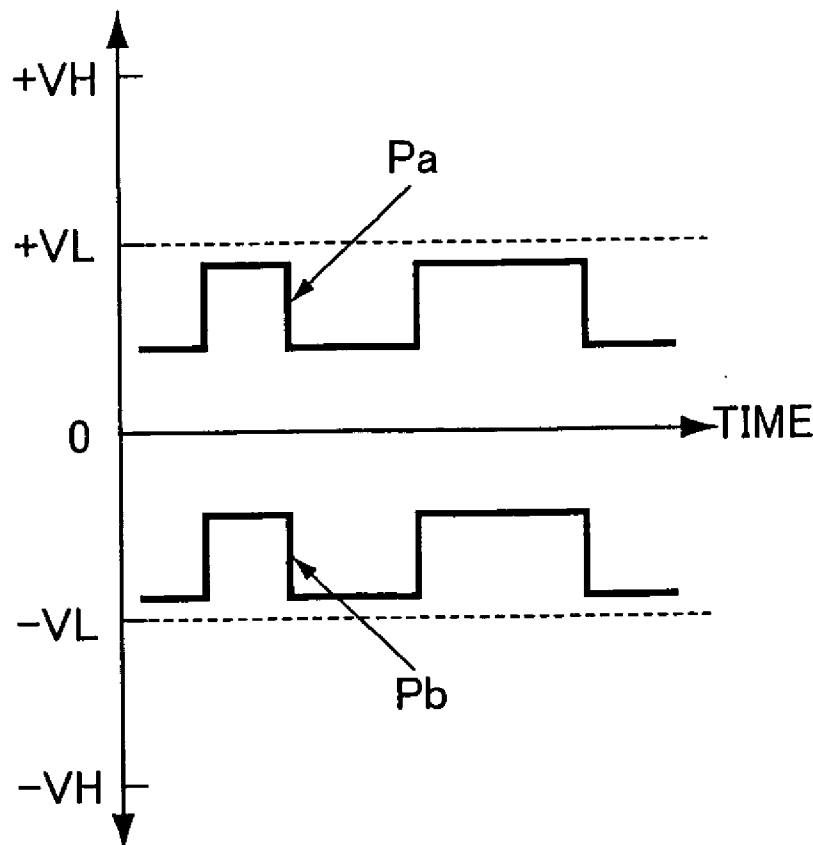
ARENT FOX PLLC**1050 CONNECTICUT AVENUE, N.W.****SUITE 400****WASHINGTON, DC 20036 (US)**(73) Assignee: **Pioneer Corporation**(21) Appl. No.: **11/195,832**(22) Filed: **Aug. 3, 2005**(30) **Foreign Application Priority Data**

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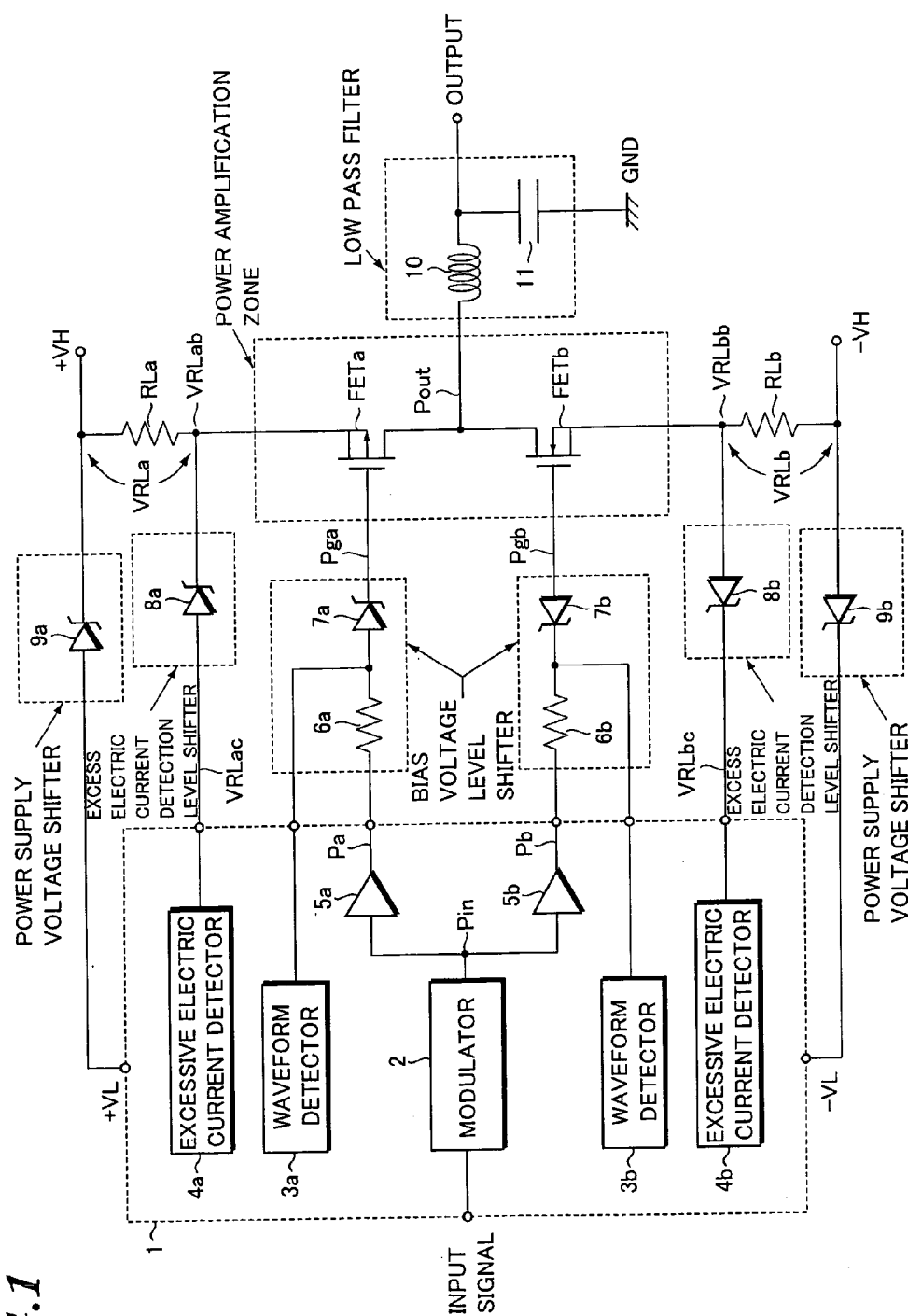
A drive signal that matches the bias of a transistor is generated. A differential amplifier calculates the difference between a specified voltage of negative power supply and another input signal. Then, a resistor that realizes a pull-down function level-shifts it towards a negative power supply voltage having a higher absolute voltage value to generate another differential signal, which is in turn amplified in another amplifier, to generate another drive signal that matches the bias of another transistor. Respective current mirror circuits detect a falling voltage occurring at both ends of a resistor connected between the transistor and the higher positive power supply voltage and a falling voltage occurring at both ends of a resistor connected between the other transistor and the higher negative power supply voltage, respectively. Then, the presence of an excessive electric current is detected by generating electric currents in accordance with to the falling voltages.

(POSITIVE VOLTAGE)



(NEGATIVE VOLTAGE)

FIG. 1



RIOR ART

FIG.2 A

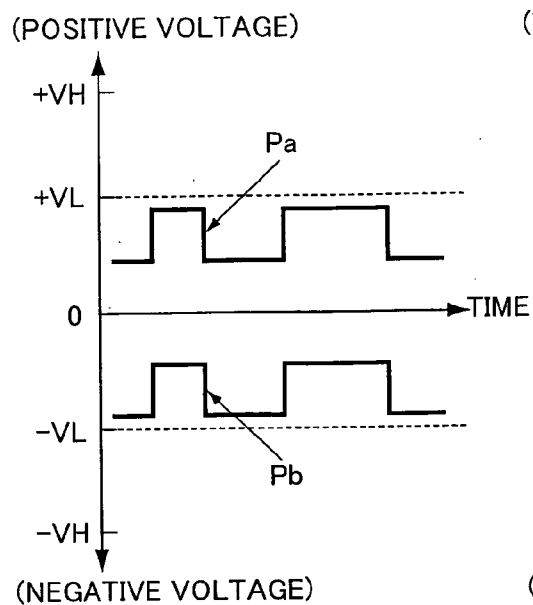


FIG.2 B

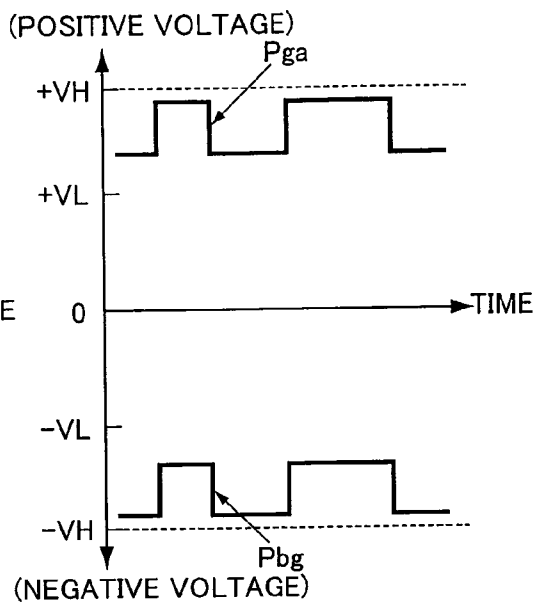


FIG.2 C

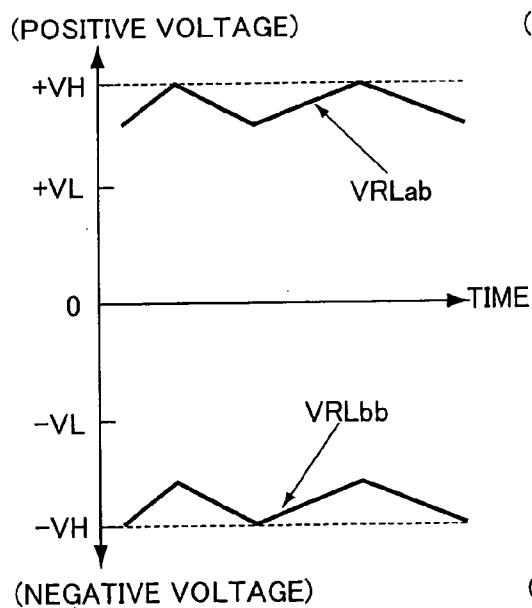
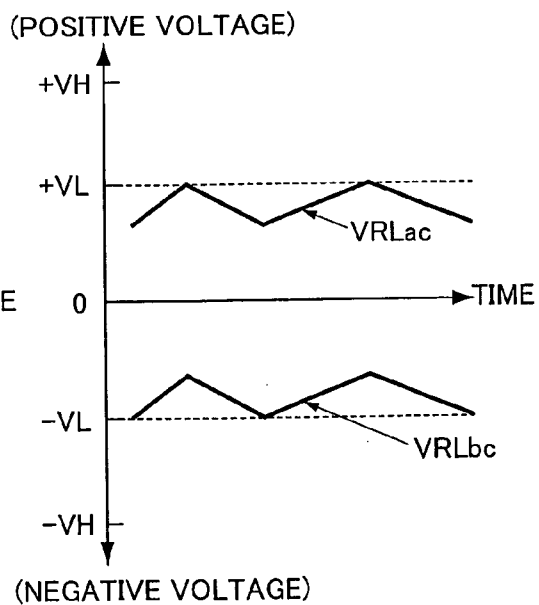


FIG.2 D



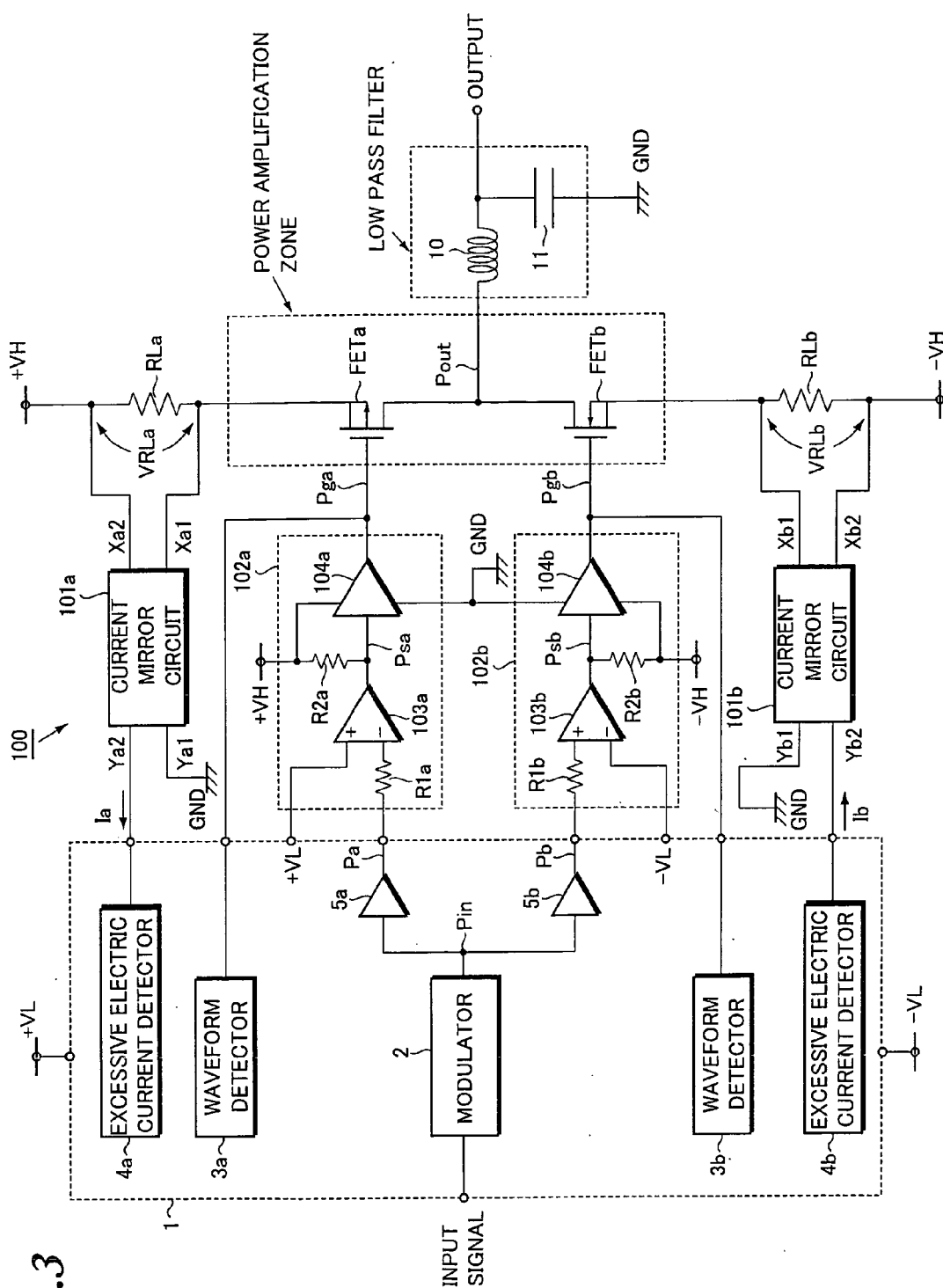


FIG.3

FIG. 4

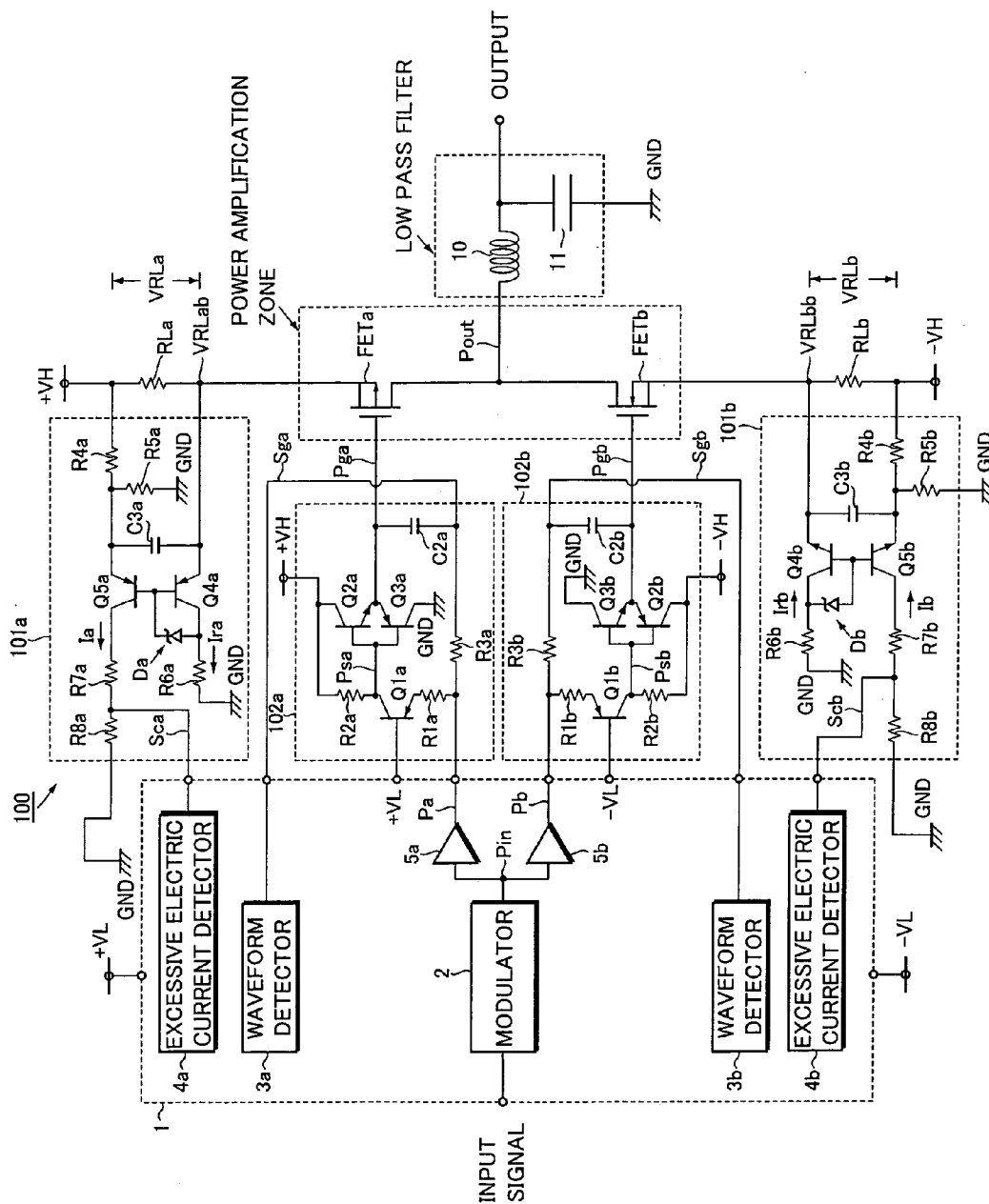


FIG.5A

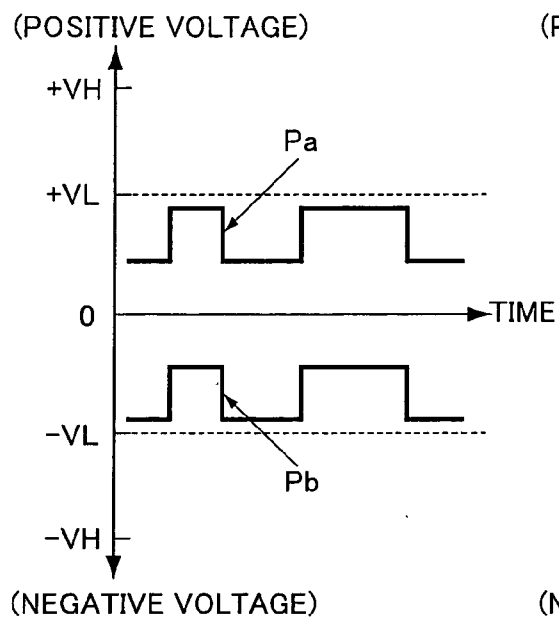


FIG.5 B

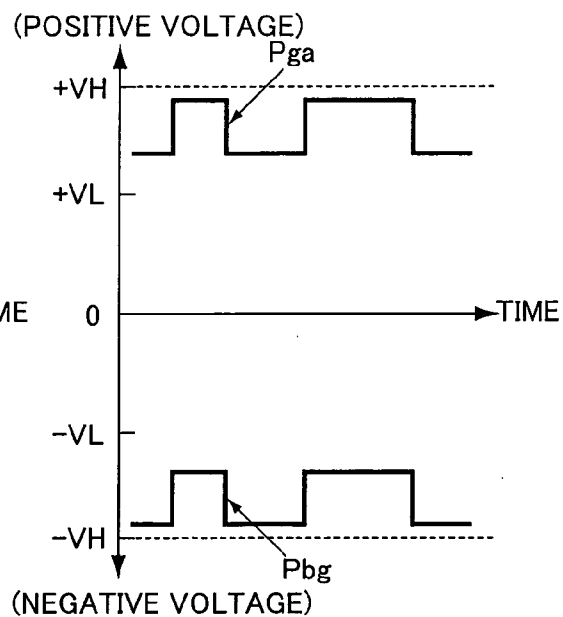
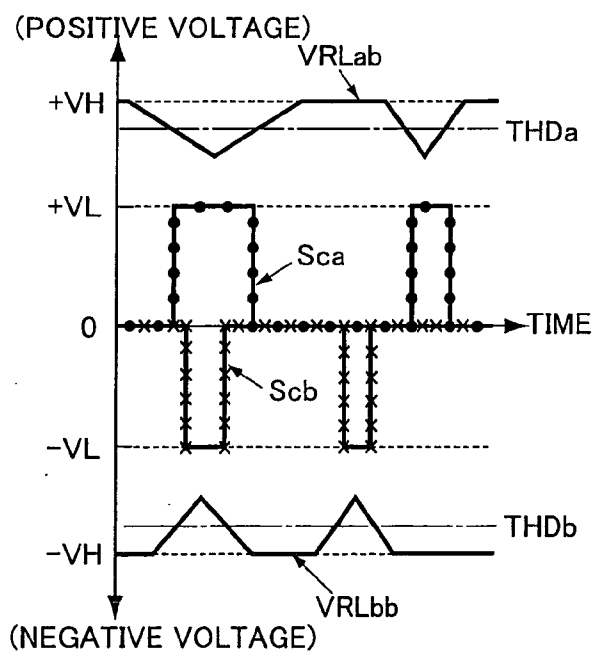


FIG.5 C



CLASS D AMPLIFIER

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a class D amplifier that amplifies square-wave signals which have undergone, for example, pulse width modulation (PWM) or pulse density modulation (PDM).

[0002] The present application claims priority from Japanese Application No. 2004-226928, the disclosure of which is incorporated herein by reference.

[0003] In recent years, simpler, smaller, and higher efficiency system configurations of audio systems performing digital signal processing have been strived for through the use of class D amplifiers. In these systems, the class D amplifiers amplify square-wave audio signals (so-called, 1-bit stream format audio signals) formed by pulse width modulation or pulse density modulation and directly supply them to speakers via a low-pass filter.

[0004] FIG. 1 is a schematic diagram that represents the configuration of a conventional class D amplifier applied to this type of digital audio system.

[0005] The class D amplifier in this figure is connected to a semiconductor integrated circuit device (IC) 1. Here, the IC 1 is equipped with a modulator 2 that converts analog input signals and PCM digital signals to 1-bit stream format signals Pin using pulse width modulation or pulse density modulation.

[0006] In other words, the semiconductor integrated circuit device 1 operates using two power supply voltages of positive power supply voltage +VL and negative power supply voltage -VL which are equal absolute potential relative to the ground potential (0 V) as a reference. In addition to the modulator 2, the device 1 includes waveform detectors 3a, 3b, excessive electric current detectors 4a, 4b, and amplifiers 5a, 5b. The amplifiers 5a and 5b amplify 1-bit stream format signals Pin and then output 1-bit stream format signals Pa and Pb (hereinafter, simply referred to as output modulated signals) respectively, to allow a P-channel field-effect transistor FETa and an N-channel field effect transistor FETb (described later) to operate in a push-pull manner.

[0007] The class D amplifier operates using two power supply voltages of positive power supply voltage +VH and negative power supply voltage -VH which are higher than power supply voltages +VL and -VL respectively, and are equal absolute potential relative to the ground potential as a reference. The class D amplifier comprises a power amplification zone formed from the P-channel field effect transistor FETa and the N-channel field effect transistor FETb, resistors 6a, 6b, RLa, and RLb, and Zener diodes 7a, 7b, 8a, 8b, 9a, and 9b.

[0008] The Zener diodes 9a and 9b which generate equal Zener voltages each form a power supply voltage shifter. These shifters supply the respective power supply voltages +VL and -VL to the semiconductor integrated circuit device 1. The power supply voltages +VL and -VL have been lowered by respective Zener voltages so as to be lower than the positive power supply voltage +VH and the negative power supply voltage -VH supplied from a main power supply (not shown in the figure).

[0009] The transistors FETa and FETb are connected through respective resistors RLa and RLb between power supply terminals for the power supply voltages +VH and -VH. The push-pull operation of the transistors FETa and FETb, which follows drive signals Pga and Pgb, outputs a power-amplified, 1-bit stream format signal (hereinafter referred to as "an output modulated signal") Pout. Thereafter, supplying this output modulated signal Pout to a low-pass filter composed of a coil 10 and a capacitor 11 converts the signal to analog audio signal Sout which is then output to a speaker, for example.

[0010] The resistors 6a and 6b are determined to be equal resistance values and the Zener diodes 7a and 7b are formed by Zener diodes which generate equal Zener voltages.

[0011] The resistor 6a and the Zener diode 7a, which form a bias voltage level shifter, apply a level shift (voltage bias) to the input modulated signal Pa based on the Zener voltage and that level-shifted drive signal Pga is supplied to the gate of the transistor FETa.

[0012] In other words, the Zener diode 7a generates the drive signal Pga, that varies within a voltage range between the ground potential and the power supply voltage +VH as shown in FIG. 2(b), by applying a positive voltage bias to the input modulated signal Pa, that varies within a voltage range between the ground potential (0 V) and the power supply voltage +VL as shown in FIG. 2(a), to adjust it to the bias condition of the transistor FETa that operates under the power supply voltage +VH.

[0013] In a similar manner, the resistor 6b and the Zener diode 7b, which form a bias voltage level shifter, apply a level shift (voltage bias) to the input modulated signal Pb based on the Zener voltage and that level-shifted drive signal Pgb is supplied to the gate of the transistor FETb.

[0014] In other words, the Zener diode 7b generates the drive signal Pgb, that varies within a voltage range between the ground potential and the power supply voltage -VH as shown in FIG. 2(b), by applying a negative voltage bias to the input modulated signal Pb that varies within a voltage range between the ground potential (0 V) and the power supply voltage -VL as shown in FIG. 2(a), to adjust it to the bias condition of the transistor FETb that operates under the power supply voltage -VH.

[0015] A connection point between the resistor 6a and the Zener diode 7a is connected to the input terminal of the waveform detector 3a. An analysis of whether or not waveform distortions are occurring in the drive signal Pga is automatically performed by supplying an output waveform of the resistor 6a to the waveform detector 3a.

[0016] Furthermore, a connection point between the resistor 6b and the Zener diode 7b is connected to the input terminal of the waveform detector 3b. An analysis of whether or not waveform distortions are occurring in the drive signal Pgb is automatically performed by supplying an output waveform of the resistor 6b to the waveform detector 3b.

[0017] The Zener diode 8a connected between the resistor RLa and the input terminal of the excessive electric current detector 4a, and the Zener diode 8b connected between the resistor RLb and the input terminal of the excessive electric current detector 4b, are provided to detect excessive electric

current flowing in the transistors FETa and FETb through the resistors RL_a and RL_b, respectively.

[0018] In other words, the Zener diode 8a forms an excess electric current detection level shifter. This level shifter level-shifts a voltage VRL_a (lowered by the falling voltage VRL_a occurring at both ends of the resistor RL_a with reference to the power supply voltage +VH as shown in FIG. 2 (c)) based on the corresponding Zener voltage and supplies it to the excessive electric current detector 4a. Then, as shown in FIG. 2 (d), the Zener diode 8a supplies a falling voltage VRL_a adjusted to the bias condition of the excessive electric current detector 4a operating under the power supply voltage +VL.

[0019] If the falling voltage VRL_a becomes larger than a predetermined allowable voltage, the excessive electric current detector 4a detects the occurrence of an excessive electric current and takes necessary steps to stop input modulated signals Pa and Pb in order to prevent a damage to the transistor FETa.

[0020] In addition, in a like manner, the Zener diode 8b forms an excess electric current detection level shifter. This level shifter level-shifts a voltage VRL_b (lowered by the falling voltage VRL_b occurring at both ends of the resistor RL_b with reference to the power supply voltage -VH as shown in FIG. 2 (c)) based on the corresponding Zener voltage and supplies it to the excessive electric current detector 4b. Then, as shown in FIG. 2 (d), the Zener diode 8b supplies a falling voltage VRL_b adjusted to the bias condition of the excessive electric current detector 4b operating under the power supply voltage -VL.

[0021] If the falling voltage VRL_b becomes larger than a predetermined allowable voltage, the excessive electric current detector 4b detects the occurrence of an excessive electric current and takes necessary steps to stop input modulated signals Pa and Pb in order to prevent a damage to the transistor FETb.

[0022] As described above, a conventional class D amplifier performs highly efficient power amplification by operating transistors FETa and FETb under high voltage power supply voltages +VL and -VL. Various types of level shifters are also provided which utilize Zener diodes 7a, 7b, 8a, and 8b, so as to perform power amplification in accordance with the respective bias conditions of the semiconductor integrated circuit device 1 that operates under power supply voltages +VL and -VL, and the class D amplifier that operates under power supply voltages +VH and -VH.

[0023] Zener diodes 7a, 7b, 8a, and 8b are provided in order for conventional class D amplifiers to perform predetermined operations in accordance with the bias conditions of the semiconductor integrated circuit device 1 and the class D amplifier as described above. In addition, Zener diodes 9a and 9b are provided in order to make different the power supply voltages +VL, -VL for the semiconductor integrated circuit device 1 and the power supply voltages +VH, -VH for the class D amplifier.

[0024] Since these Zener diodes 7a, 7b, 8a, 8b, 9a, 9b do not always generate equal Zener voltages for each set due to their electrical and other properties, there were problems of variations in the Zener voltages (manufacturing variations, fluctuations during operation, and the like), hence making it

impossible for the class D amplifiers to perform the predetermined operations that are adjusted to the bias conditions described above.

[0025] In other words, if variations occur in the Zener voltage between the Zener diode 7a that forms the bias voltage level shifter of the power supply voltage +VH side in FIG. 1 and the Zener diode 7b that forms the bias voltage level shifter of the power supply voltage -VH side in FIG. 1, the bias points of the drive signals P_{ga} and P_{gb} respectively supplied to the transistors FETa and FETb which operate in a push-pull manner, will shift away from the correct bias as illustrated in FIG. 2(b), causing problems such as waveform distortions in the output modulated signal P_{out} and the inability to perform efficient power amplification. As a result of the bias points of the drive signals P_{ga}, P_{gb} shifting away from the correct bias, a load that exceeds the allowable power loss is applied to at least one of the transistors FETa and FETb, which leads to a problem of the transistors being easily damaged.

[0026] Even further, even if the Zener voltages of both the Zener diodes 7a and 7b are shifted from the correct Zener voltage, problems will occur such as waveform distortions in the output modulated signal P_{out}, inability to perform efficient power amplification, and damage to transistors FETa, FETb.

[0027] If variations occur in the Zener voltage of the Zener diode 8a that forms the excessive electric current detection level shifter of the positive power supply voltage +VH side, an offset voltage will be applied to the falling voltage VRL_a as illustrated in FIG. 2 (d) generating a voltage fluctuation and consequently causing a problem of the excessive electric current detector 4a not being able to correctly detect the excessive electric current flowing in the transistor FETa.

[0028] If variations occur in the Zener voltage of the Zener diode 8b that forms the excessive electric current detection level shifter of the positive power supply voltage -VH side, an offset voltage will be applied to the falling voltage VRL_b as illustrated in FIG. 2 (d), generating a voltage fluctuation and consequently causing a problem of the excessive electric current detector 4b not being able to correctly detect the excessive electric current flowing in the transistor FETb.

[0029] When variations in the Zener voltage occur in the Zener diodes 9a and 9b each forming a power supply voltage shifter, a problem occurs in which it becomes impossible to operate the semiconductor integrated circuit device 1 based on the correct voltage of two power supply voltages +VL and -VL.

SUMMARY OF THE INVENTION

[0030] In view of the foregoing conventional problems, an object of the present invention is to provide a class D amplifier having bias voltage level shift means that can suitably level-shift the bias of drive signals to be supplied to switching elements that form a power amplification zone and operate in a push-pull manner.

[0031] Another object of the present invention is to provide a class D amplifier having excessive electric current detection means that can accurately detect excessive electric current flowing in switching elements that form a power amplification zone and operate in a push-pull manner.

[0032] According to a first aspect of the present invention, a class D amplifier comprises: a pair of switching elements composed of first and second switching elements which are complementally symmetrical with respect to a voltage of a power supply; first bias voltage level shift means that generates a drive signal to be supplied to the first switching element by level-shifting a square-wave first input signal; and second bias voltage level shift means that generates a drive signal to be supplied to the second switching element by level-shifting a square-wave second input signal. Such class D amplifier is provided for performing class D amplification by allowing the first and second switching elements to perform a push-pull operation based on the respective drive signals supplied thereto. In particular, the first bias voltage level shift means has first differential amplification means that calculates a differential signal between the first input signal and a predetermined voltage, and first bias means that generates a level-shifted drive signal to be supplied to the first switching element by pulling up the differential signal towards the power supply voltage of the first switching element. Further, the second bias voltage level shift means has second differential amplification means that calculates a differential signal between the second input signal and a predetermined voltage, and second bias means that generates a level-shifted drive signal to be supplied to the second switching element by pulling down the differential signal towards the power supply voltage of the second switching element.

[0033] According to a second aspect of the present invention, there is provided a class D amplifier having a pair of switching elements composed of first and second switching elements which are complementally symmetrical with respect to a voltage of a power supply, the class D amplifier being provided for performing class D amplification by allowing the first and second switching elements to perform a push-pull operation based on the respective square-wave drive signals supplied thereto. Such class D amplifier comprises: a first resistor connected between the first switching element and the power supply; a second resistor connected between the second switching element and the power supply; a first current mirror circuit that receives a falling voltage generated at both ends of the first resistor and generates an electric current corresponding to the falling voltage; and a second current mirror circuit that receives a falling voltage generated at both ends of the second resistor and generates an electric current corresponding to the falling voltage. In particular, the respective currents output from the first and second current mirror circuits serve as an excessive electric current detection current that shows whether or not excessive electric currents flow in the first and second switching elements.

[0034] According to a third aspect of the present invention, a class D amplifier comprises: a pair of switching elements composed of first and second switching elements which are complementally symmetrical with respect to a voltage of a power supply; first bias voltage level shift means that generates a drive signal to be supplied to the first switching element by level-shifting a square-wave first input signal; and second bias voltage level shift means that generates a drive signal to be supplied to the second switching element by level-shifting a square-wave second input signal. Such class D amplifier is provided for performing class D amplification by allowing the first and second switching elements to perform a push-pull operation based

on the respective drive signals supplied thereto. In particular, the class D amplifier further comprises: a first resistor connected between the first switching element and the power supply; a second resistor connected between the second switching element and the power supply; a first current mirror circuit that receives a falling voltage generated at both ends of the first resistor and generates an electric current corresponding to the falling voltage; and a second current mirror circuit that receives a falling voltage generated at both ends of the second resistor and generates an electric current corresponding to the falling voltage. Further, the first bias voltage level shift means has first differential amplification means that calculates a differential signal between the first input signal and a predetermined voltage, and first bias means that generates a level-shifted drive signal to be supplied to the first switching element by pulling up the differential signal towards the power supply voltage of the first switching element. Moreover, the second bias voltage level shift means has second differential amplification means that calculates a differential signal between the second input signal and a predetermined voltage, and second bias means that generates a level-shifted drive signal to be supplied to the second switching element by pulling down the differential signal towards the power supply voltage of the second switching element.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] These and other objects and advantages of the present invention will become clear from the following description with reference to the accompanying drawings, wherein:

[0036] **FIG. 1** is a circuit diagram showing the configuration of a conventional class D amplifier;

[0037] **FIG. 2** describes the operation of the bias voltage level shifter and the excess electric current detection level shifter provided in the conventional class D amplifier shown **FIG. 1**;

[0038] **FIG. 3** is a block diagram showing the configuration of a class D amplifier according to one embodiment of the present invention;

[0039] **FIG. 4** is a circuit diagram showing the exemplary configuration of a class D amplifier according to the present invention; and

[0040] **FIG. 5** describes the operation of the class D amplifier shown in **FIG. 4**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0041] In the following, embodiments of the present invention will be described in detail with reference to **FIG. 3**. **FIG. 3** is a block diagram showing the configuration of a class D amplifier according to the present embodiment.

[0042] The configuration of the class D amplifier **100** of this embodiment in this figure will first be described. As an example, the class D amplifier **100** amplifies power based on first and second input modulated waves (signals which have undergone PWM or PDM modulation) Pa and Pb (which are 1-bit stream format, output from a semiconductor integrated circuit device **1** as mentioned in the description of the conventional technology) and then outputs the 1-bit stream

format modulated signal P_{out} that has undergone power amplification. Then, the output modulated signal P_{out} is supplied to a low pass filter composed of a coil **10** and a capacitor to thereby be converted to an analog audio signal S_{out} . This signal can directly drive devices such as speakers.

[0043] The class D amplifier **100** is connected to a detection circuit or a sensing circuit which correspond to waveform detectors **3a**, **3b** or excessive electric current detectors **4a**, **4b** provided in the semiconductor integrated circuit device **1** mentioned in the description of the conventional technology.

[0044] In other words, although not limited to a semiconductor integrated circuit device **1** mentioned in the description of the conventional technology, the class D amplifier **100** is designed such that it outputs signals to allow a detection circuit or a detecting circuit (which correspond to waveform detectors **3a**, **3b** and excessive electric current detectors **4a**, **4b**) to detect waveforms of drive signals P_{ga} and P_{gb} and also detect the generation of excessive electric current.

[0045] Next, the configuration of the class D amplifier **100** will be described.

[0046] This class D amplifier **100** can operate at a voltage higher than the two power supply voltages $+V_L$ and $-V_L$ for the semiconductor integrated circuit device **1** and receives a supply of a positive power supply voltage $+V_H$ and a negative power supply voltage $-V_H$ both of which are equal to the absolute value of the voltage between positive and negative with reference to the ground potential (0 V). The positive power supply voltage $+V_H$ and the negative power supply voltage $-V_H$ are supplied from a power supply circuit (not shown in the figure) separate from the two power supply voltages $+V_L$ and $-V_L$.

[0047] The class D amplifier **100** comprises a pair of switching elements, current mirror circuits **101a** and **101b**, and bias voltage level shifters **102a** and **102b**. The pair of switching elements are provided between the respective power supply terminals of the positive power supply voltage $+V_H$ and the negative power supply voltage $-V_H$. This pair of switching elements are composed of a P-channel field effect transistor FETa that serves as a first switching element and an N-channel field effect transistor FETb that serves as a second switching element. These first and second switching elements are complementally symmetrical with respect to the power supply voltage. The current mirror circuits **101a** and **101b** serve as excessive electric current detection means.

[0048] The bias voltage level shifter **102a** comprises a differential amplifier **103a**, a resistor **R2a**, and a voltage amplifier **104a**. The differential amplifier **103a** receives the input modulated signal P_a supplied through resistor **R1a** from an amplifier **5a** provided in the semiconductor integrated circuit device **1** and then outputs a differential signal that corresponds to the voltage difference between the input modulated signal P_a and the positive power supply voltage $+V_L$. The resistor **R2a** is connected between the power supply terminal of the positive power supply voltage $+V_H$ and the output terminal (output terminal where differential signals are output) of the differential amplifier **103a**. The voltage amplifier **104a** performs voltage amplification of a signal P_{sa} generated at the output terminal of the differential

amplifier **103a** and then generates the drive signal P_{ga} to be supplied to the gate of the transistor FETa.

[0049] Here, the resistor **R2a** serves as first bias means that realizes a function that connects the power supply terminal of the positive power supply voltage $+V_H$ to the output terminal of the differential amplifier **103a**, thereby pulling up the potential of the output terminal of the differential amplifier **103a** towards the positive power supply voltage $+V_H$.

[0050] Consequently, the above-mentioned differential signal occurring at the output terminal of the differential amplifier **103a**, or namely, this differential signal generated at the differential amplifier **103a** with reference to the positive power supply voltage $+V_L$, is level-shifted by the pull-up function of the resistor **R2a** to the signal P_{sa} (whose amplitude varies between the positive power supply voltage $+V_H$ and the ground potential, with the positive power supply voltage $+V_H$ as a reference value) and is then supplied to the voltage amplifier **104a**.

[0051] When designing the class D amplifier **100** of this embodiment, the resistance ratio between the resistor **R1a** connected to the input of the differential amplifier **103a**, and the resistor **R2a** that realizes a pull-up function is determined to be a specified value and the bias of the signal P_{sa} is set to a specified potential. This makes it possible to always stabilize the bias potential of the drive signal P_{ga} as well as adjust the bias to a gate bias point suitable to operate the transistor FETa in a push-pull manner.

[0052] In other words, in like manner to FIG. 2(a) and 2(b), the bias voltage level shifter **102a** makes it possible to level shift a square-wave input modulated signal P_a , that varies within a voltage range between the ground potential and the positive power supply voltage $+V_L$, to a square-wave drive signal P_{ga} , that varies within a voltage range between the ground potential and the positive power supply voltage $+V_H$ and always stabilize the bias voltage as that level-shifted quantity.

[0053] Moreover, forming electrical wiring that should supply the drive signal P_{ga} to the waveform detector **3a** allows the waveform detector **3a** to analyze for the presence of waveform distortions in the drive signal P_{ga} .

[0054] Next, the configuration of the bias voltage level shifter **102b** will be described.

[0055] The bias voltage level shifter **102b** comprises a differential amplifier **103b**, a resistor **R2b**, and a voltage amplifier **104b**. The differential amplifier **103b** receives the input modulated signal P_b supplied through resistor **R1b** from an amplifier **5b** provided in the semiconductor integrated circuit device **1** and then outputs a differential signal that corresponds to the voltage difference between the input modulated signal P_b and the negative power supply voltage $-V_L$. The resistor **R2b** is connected between the power supply terminal of the negative power supply voltage $-V_H$ and the output terminal (output terminal where differential signals are output) of the differential amplifier **103b**. The voltage amplifier **104b** performs voltage amplification of a signal P_{sb} generated at the output terminal of the differential amplifier **103b** and then generates the drive signal P_{gb} to be supplied to the gate of the transistor FETb.

[0056] Here, the resistor **R2b** serves as second bias means that realizes a function that connects the power supply

terminal of the negative power supply voltage $-V_H$ to the output terminal of the differential amplifier **103b**, thereby pulling down the potential of the output terminal of the differential amplifier **103b** towards the negative power supply voltage $-V_H$.

[0057] Consequently, the above-mentioned differential signal occurring at the output terminal of the differential amplifier **103b**, or namely, this differential signal generated at the differential amplifier **103b** with reference to the negative power supply voltage $-V_L$, is level-shifted by the pull-down function of the resistor **R2b** to the signal P_{sb} (whose amplitude varies between the negative power supply voltage $-V_H$ and the ground potential, with the negative power supply voltage $-V_H$ as a reference value) and is then supplied to the voltage amplifier **104b**.

[0058] When designing the class D amplifier **100** of this embodiment, the resistance ratio between the resistor **R1b** connected to the input of the differential amplifier **103b**, and the resistor **R2b** that realizes a pull-down function is determined to be a specified value and the bias of the signal P_{sb} is set to a specified potential. This makes it possible to always stabilize the bias potential of the drive signal P_{gb} as well as adjust the bias to a gate bias point suitable to operate the transistor **FETb** in a push-pull manner.

[0059] In other words, in like manner to **FIG. 2(a)** and **2(b)**, the bias voltage level shifter **102b** makes it possible to level shift a square-wave input modulated signal P_b , that varies within a voltage range between the ground potential and the negative power supply voltage $-V_L$, to a square-wave drive signal P_{gb} , that varies within a voltage range between the ground potential and the negative power supply voltage $-V_H$ and always stabilize the bias voltage as that level-shifted quantity.

[0060] Moreover, forming electrical wiring that should supply the drive signal P_{gb} to the waveform detector **3b** allows the waveform detector **3b** to analyze for the presence of waveform distortions in the drive signal P_{gb} .

[0061] Next, the configuration of the current mirror circuit **101a** will be described.

[0062] This current mirror circuit **101a** operates within a voltage range between the positive power supply voltage $+V_H$ and the ground potential. The current mirror circuit **101a** has two input terminals X_{a1} and X_{a2} connected to respective ends of the resistor **RLa**, an output terminal Y_{a1} connected to the ground terminal **GND**, and an output terminal Y_{a2} connected to the excessive electric current detector **4a**. A transistor pair (not shown in figure) is connected between these input terminals X_{a1} , X_{a2} and output terminals Y_{a1} , Y_{a2} and operates as a current mirror.

[0063] In other words, this transistor pair is formed by, for example, two PNP transistors whose bases are connected together while one of the PNP transistors has a collector connected a base thereof.

[0064] The emitter of the PNP transistor whose collector and base are connected (PNP transistor that essentially functions as a diode and is referred to as a "first PNP transistor" hereinafter) is connected to an input terminal X_{a1} . A resistor with a specified value (hereinafter referred to as a "reference current setting resistor") is connected between the collector of the first PNP transistor and the

output terminal Y_{a1} . Moreover, the emitter of the other PNP transistor of the transistor pair (hereinafter referred to as a "second PNP transistor") is connected to the input terminal X_{a2} and the collector of the second PNP transistor is connected to the excessive electric current detector **4a** through the output terminal Y_{a2} .

[0065] The surface area (emitter size) of the emitter of the second PNP transistor connected between the input terminal X_{a2} and the output terminal Y_{a2} is smaller compared to the surface area (emitter size) of the emitter of the first PNP transistor connected between the input terminal X_{a1} and the output terminal Y_{a1} .

[0066] As a result, compared to the voltage between the base and the emitter required to operate the first PNP transistor in an ON state, the voltage between the base and the emitter required to operate the second PNP transistor in an ON state is higher and the deadband of the second PNP transistor is larger. The voltage of this deadband is employed as a threshold value to detect an excessive electric current.

[0067] In the current mirror circuit **101a** with such a configuration described above, an electric current I_{ra} flows from the resistor **RLa** to the input terminal X_{a1} and then flows to the ground through the first PNP transistor (PNP transistor that functions as a diode), the reference current setting resistor, and the output terminal Y_{a1} . This electric current I_{ra} is employed as a reference electric current with a specified electric current value.

[0068] Almost no electric current flows in the second PNP transistor, that has a deadband, until an excessive electric current is flowing in the resistor **RLa**. On the other hand however, if an excessive electric current is flowing in the resistor **RLa**, the second PNP transistor will turn ON by applying a higher voltage than the voltage of the deadband between the base and the emitter of the second PNP transistor as falling voltage V_{RLa} , that occurs at the resistor **RLa**, becomes larger. Then, the excessive electric current detection current I_a , that functions as an excessive electric current detection signal nearly proportional to the excessive electric current, is output from the second PNP transistor to the excessive electric current detector **4a** through the output terminal Y_{a2} .

[0069] In this manner, the current mirror circuit **101a** can detect an excessive electric current flowing in the transistor **FETa** through the resistor **RLa** and can supply that detection information to the excessive electric current detector **4a**.

[0070] Since the collector of the second PNP transistor is connected to this excessive electric current detector **4a**, the output impedance is extremely high for the excessive electric current detector **4a** (namely, functions as a constant-current power source). Because of this, even if the voltages of the power supply voltages $+V_L$, $-V_L$ and the voltages of the power supply voltages $+V_H$, $-V_LH$ are different, it is possible to make a process that performs level shifting the detected excessive electric current to an excessive electric current detection current I_a essentially unnecessary and also to reliably supply the excessive electric current detection current I_a , that shows the excessive electric current detection information, to the excessive electric current detector **4a**.

[0071] Although the configuration that supplies an excessive electric current detection current I_a to the excessive electric current detector **4a** was described, a resistor that

functions as a current-voltage converter can be connected between the collector of the second PNP transistor and the excessive electric current detector **4a**. The excessive electric current detection current **Ia** can then undergo current-voltage conversion to become an excessive electric current detection voltage which is then supplied to the excessive electric current detector **4a**.

[0072] Furthermore, although a description was provided when using a transistor pair composed of two PNP transistors to form the current mirror circuit **101a**, another transistor can be used to form the current mirror circuit such as a field-effect transistor.

[0073] Next, the configuration of the current mirror circuit **101b** will be described.

[0074] This current mirror circuit **101b** operates within a voltage range between the negative power supply voltage $-VH$ and the ground potential. The current mirror circuit **101b** also has a configuration identical to the current mirror circuit **101a**.

[0075] Namely, in place of the first PNP transistor and the second PNP transistor, the current mirror circuit **101b** has a transistor pair commonly connected between both bases of a first NPN transistor (not shown in figure) and a second NPN transistor (not shown in figure).

[0076] The emitter of the first NPN transistor (NPN transistor whose base and collector are connected to function as a diode) is connected to a connection point between the resistor **RLb** and the transistor **FETb** through the input terminal **Xb1**. Furthermore, the second NPN transistor is connected at its collector to the ground terminal **GND** through a reference current setting resistor identical to the above-mentioned reference current setting resistor provided in the current mirror circuit **101a** and also through the output terminal **Yb1**.

[0077] In contrast, the emitter of the second NPN transistor is connected to the power supply voltage $-VH$ of the resistor **RLb** through the input terminal **Xb2** and the collector of the second NPN transistor is connected to the excessive electric current detector **4b**.

[0078] The surface area of the emitter of the second NPN transistor connected between the input terminal **Xb2** and the output terminal **Yb2** is smaller compared to the surface area of the emitter of the first NPN transistor connected between the input terminal **Xb1** and the output terminal **Yb1**.

[0079] As a result, compared to the voltage between the base and the emitter required to operate the first NPN transistor in an ON state, the voltage between the base and the emitter required to operate the second NPN transistor in an ON state is higher and the deadband of the second NPN transistor is larger. The voltage of this deadband is employed as a threshold value to detect an excessive electric current.

[0080] In the current mirror circuit **101b** with such a configuration described above, an electric current **Irb** flows from the ground terminal **GND** to the first NPN transistor (NPN transistor that functions as a diode). This electric current **Irb** is employed as a reference electric current with a specified electric current value.

[0081] Almost no electric current flows in the second NPN transistor, that has a deadband, until an excessive electric

current is flowing in the resistor **RLb**. On the other hand however, if an excessive electric current is flowing in the resistor **RLb**, the second NPN transistor will turn ON by applying a higher voltage than the voltage of the deadband between the base and the emitter of the second NPN transistor as falling voltage **VRLa**, that occurs at the resistor **RLa**, becomes larger. Then, the excessive electric current detection current **Ib** (namely, sink current (absorption current)), that functions as an excessive electric current detection signal nearly proportional to the excessive electric current, is supplied from the second NPN transistor to the excessive electric current detector **4b** through the output terminal **Yb2**.

[0082] In other words, an identical operation is performed in which an excessive electric current detection current **Ib** is supplied to the excessive electric current detector **4b** because the second NPN transistor sinks the excessive electric current detection current **Ib**.

[0083] In this manner, the current mirror circuit **101b** can detect an excessive electric current flowing in the transistor **FETb** through the resistor **RLb** and supply that detection information to the excessive electric current detector **4b**.

[0084] Since the collector of the second NPN transistor is connected to this excessive electric current detector **4b**, the output impedance is extremely high for the excessive electric current detector **4b** (namely, functions as a constant-current power source). Because of this, even if the voltages of the power supply voltages $+VL$, $-VL$ and the voltages of the power supply voltages $+VH$, $-VH$ are different, it is possible to detect an excessive electric current flowing in the transistor **FETb** and to reliably supply an excessive electric current detection current **Ib**, that shows the excessive electric current detection information, to the excessive electric current detector **4b**.

[0085] Although the configuration that supplies an excessive electric current detection current **Ib** to the excessive electric current detector **4b** was described, a resistor that functions as a current-voltage converter can be connected between the collector of the second NPN transistor and the excessive electric current detector **4b**. The excessive electric current detection current **Ib** can then undergo current-voltage conversion to become an excessive electric current detection voltage which is then supplied to the excessive electric current detector **4b**.

[0086] Furthermore, although a description was provided when using a transistor pair composed of two NPN transistors to form the current mirror circuit **101b**, another transistor can be used to form the current mirror circuit such as a field-effect transistor.

[0087] According to the class D amplifier **100** of the present embodiment as described above, drive signals **Pga**, **Pgb** which are at a bias point suitable for the transistors **FETa**, **FETb** to operate in a push-pull manner can be supplied to these transistors **FETa**, **FETb** because the bias voltage level shifters **102a** and **102b**, that generate level-shifted signals **Psa** and **Psb**, are provided. Here, the bias voltage level shifter **102a** uses the resistor **R2a** to pull up a differential signal, that corresponds to the difference between the input modulated signal **Pa** and the positive power supply voltage $+VL$, to the positive power supply voltage $+VH$ as well as the bias voltage level shifter **102b**

uses the resistor **R2b** to pull down a differential signal, that corresponds to the difference between the input modulated signal **Pb** and the negative power supply voltage $-V_L$, to the negative power supply voltage $-V_H$.

[0088] As a result, an output modulated signal **Pout** can be output from the transistors **FETa** and **FETb** without any waveform distortions, making it possible to perform efficient power amplification. Moreover, it is also possible to prevent a load that exceeds the allowable power loss from being applied to the transistors **FETa** and **FETb**, thereby making it possible to prevent a state in which damage to the transistors occurs.

[0089] Because the current mirror circuits **101a** and **101b**, which serve as excessive electric current detection means, have a high output impedance for the excessive electric current detectors **4a** and **4b**, even if the power supply voltages $+V_L$, $-V_L$ and the power supply voltages $+V_H$, $-V_H$ are different, it is possible to make a process that performs level shifting the detected excessive electric current to the excessive electric current detection currents **Ia**, **Ib** essentially unnecessary. As a result, excessive electric current detection means can be provided that has a new configuration and does not require taking into consideration variations in level shifts due to Zener diodes which has been a problem with conventional technology. It is also possible to reliably supply excessive electric current detection currents **Ia** and **Ib**, which indicate that an excessive electric current is flowing in the transistors **FETa** and **FETb**, to the excessive electric current detectors **4a** and **4b**.

EXAMPLE

[0090] Next, a concrete example will be described in more detail with reference to **FIG. 4** and **FIG. 5**.

[0091] **FIG. 4** is a schematic diagram showing the configuration of the class D amplifier **100** of the example. Parts identical or equivalent to those showing in **FIG. 3** are denoted by the same symbols. **FIG. 5** describes the operation of the class D amplifier **100** of this example. In particular, **FIGS. 5(a)** and **5(b)** describe the operation of the bias voltage level shifters **102a** and **102b** (described later) and **FIG. 5(c)** describes the operation of the current mirror circuits **101A** and **101B** which serve as excessive electric current detection means (described later).

[0092] In the following the characteristic parts of the configuration of the class D amplifier **100** in this example is described compared with the class D amplifier according to the embodiment shown in **FIG. 3**.

[0093] The bias voltage level shifter **102a** provided in the class D amplifier **100** of this example comprises resistors **R1a** and **R2a**, an NPN transistor **Q1a**, and a push-pull circuit composed of an NPN transistor **Q2a** and a PNP transistor **Q3a**.

[0094] Now, wiring is formed such that the positive power supply voltage $+V_L$ is applied to the base of the NPN transistor **Q1a** and the input modulated signal **Pa**, output from the amplifier **5a** of the semiconductor integrated circuit device **1**, is input to the emitter of the NPN transistor **Q1a** through the resistor **R1a**. In addition, the collector of the NPN transistor **Q1a** is connected to the power supply terminal of the positive power supply voltage $+V_H$ through the resistor **R2a**.

[0095] The circuit configuration obtained by the resistors **R1a** and **R2a** and the NPN transistor **Q1a** realizes a circuit that has a differential amplifier **103a**, mentioned in the description of the embodiment, and a resistor **R1b** that exhibits a pull-up function.

[0096] The push-pull circuit composed of the NPN transistor **Q2a** and the PNP transistor **Q3a** which operate within a voltage range between the positive power supply voltage $+V_H$ and the ground potential realizes the voltage amplifier **104a** mentioned in the description of the embodiment.

[0097] When the input modulated signal **Pa** is input to the NPN transistor **Q1a** through the resistor **R1a**, the NPN transistor **Q1a** generates a collector current corresponding to the difference between the input modulated signal **Pa** and the positive power supply voltage $+V_L$ which in turn allows to generate a differential signal that is proportional to the collector current at both ends of the resistor **R1a**. Because the resistor **R1a** is connected to the power supply terminal of the positive power supply voltage $+V_H$, a function that pulls up the collector potential of the NPN transistor **Q1a** is achieved and the above-mentioned differential signal that occurs at the collector of the NPN transistor **Q1a** is supplied to the push-pull circuit composed of the NPN transistor **Q2a** and the PNP transistor **Q3a** as a signal **Psa** level-shifted towards the positive power supply voltage $+V_H$ side. Then, the drive signal **Pga** to be supplied to the gate of the P-channel field-effect transistor **FETa** is generated.

[0098] In this manner, the bias voltage level shifter **102a** can generate the signal **Psa** proportional to the differential signal (collector current) that corresponds to the difference between the positive power supply voltage $+V_L$ and the input modulated signal **Pa** using the circuit composed of the NPN transistor **Q1a** and the resistors **R1a** and **R2a** as well as use the resistor **R2a** to stabilize a bias voltage corresponding to the level-shifted quantity of the signal **Psa**. Consequently, as illustrated in **FIG. 5(a)** and **5(b)**, it is possible to match the bias point of the drive signal **Pga**, that maintains a similar relationship with the waveform of the input modulated signal **Pa**, to a gate bias point suitable to operate the transistor **FETa** in a push-pull manner.

[0099] A resistor **R3a** and a capacitor **C2a** are connected in series between both emitters of the NPN transistor **Q2a** and the PNP transistor **Q3a**, and the amplifier **5a**. The connection point between the resistor **R3a** and the capacitor **C2a** is connected to the waveform detector **3a**. A signal **Sga** (hereinafter referred to as a "mixed signal") is generated by superimposing the alternating-current component of the drive signal **Pga** onto the direct-current component of the input modulated signal **Pa** at the connection point between the resistor **R3a** and the capacitor **C2a** by means of forming the related circuit configuration and wiring.

[0100] Because this mixed signal **Sga** is a signal equal to the level-shifted drive signal **Pga** that matches the so-called operating point of the waveform detector **3a** that operates between the positive power supply voltage $+V_L$ and the ground potential, the waveform detector **3a** is allowed to analyze signal waveforms which are input into the gate of the transistor **FETa**.

[0101] Next, the configuration of bias voltage level shifter **102b** of this embodiment will be described.

[0102] This bias voltage level shifter **102b** has a configuration identical to the bias voltage level shifter **102a** and has

resistors **R1b** and **R2b**, a PNP transistor **Q1b**, a push-pull circuit composed of an NPN transistor **Q3b** and a PNP transistor **Q2b**.

[0103] Now, wiring is formed such that the negative power supply voltage $-V_L$ is applied to the base of the PNP transistor **Q1b** and the input modulated signal **Pb**, output from the amplifier **5b** of the semiconductor integrated circuit device **1**, is input to the emitter of the PNP transistor **Q1b** through the resistor **R1b**. In addition, the collector of the PNP transistor **Q1b** is connected to the power supply terminal of the negative power supply voltage $-V_H$ through the resistor **R2b**.

[0104] The circuit configuration obtained by the resistors **R1b** and **R2b** and the PNP transistor **Q1b** realizes a circuit that has a differential amplifier **103b**, mentioned in the description of the embodiment, and a resistor **R2b** that exhibits a pull-down function.

[0105] The push-pull circuit composed of the NPN transistor **Q3b** and the PNP transistor **Q2b** which operate within a voltage range between the negative power supply voltage $-V_H$ and the ground potential realizes the voltage amplifier **104b** mentioned in the description of the embodiment.

[0106] When the input modulated signal **Pb** is input to the PNP transistor **Q1b** through the resistor **R1b**, the NPN transistor **Q1a** generates a collector current corresponding to the difference between the input modulated signal **Pb** and the negative power supply voltage $-V_L$ which in turn allows to generate a differential signal that is proportional to the collector current at both ends of the resistor **R2b**. Because the resistor **R2b** is connected to the power supply terminal of the negative power supply voltage $-V_H$, a function that pulls down the collector potential of the PNP transistor **Q1b** is achieved and the above-mentioned differential signal that occurs at the collector of the PNP transistor **Q1b** is supplied to the push-pull circuit composed of the NPN transistor **Q3b** and the PNP transistor **Q2b** as a signal **Psb** level-shifted towards the negative power supply voltage $-V_H$. Then, the drive signal **Pgb** to be supplied to the gate of the N-channel field-effect transistor **FETb** is generated.

[0107] In this manner, the bias voltage level shifter **102b** can generate the signal **Psb** proportional to the differential signal (collector current) that corresponds to the difference between the negative power supply voltage $-V_L$ and the input modulated signal **Pb** using the circuit composed of the PNP transistor **Q1b** and the resistors **R1b** and **R2b** as well as use the resistor **R2b** to stabilize a bias voltage corresponding to the level-shifted quantity of the signal **Psb**. Consequently, as illustrated in FIGS. **5(a)** and **5(b)**, it is possible to match the bias point of the drive signal **Pgb**, that maintains a similar relationship with the waveform of the input modulated signal **Pb**, to a gate bias point suitable to operate the transistor **FETb** in a push-pull manner.

[0108] A resistor **R3b** and a capacitor **C2b** are connected in series between both emitters of the NPN transistor **Q3b** and the PNP transistor **Q2b**, and the amplifier **5b**. The connection point between the resistor **R3b** and the capacitor **C2b** is connected to the waveform detector **3b**. A signal **Sgb** (mixed signal) is generated by superimposing the alternating-current component of the drive signal **Pgb** onto the direct-current component of the input modulated signal **Pb** at the connection point between the resistor **R3b** and the capacitor **C2b** by means of forming the related circuit configuration and wiring.

[0109] Because this mixed signal **Sgb** is a signal equal to the level-shifted drive signal **Pgb** that matches the so-called operating point of the waveform detector **3b** that operates between the negative power supply voltage $-V_L$ and the ground potential, the waveform detector **3b** is allowed to analyze signal waveforms which are input into the gate of the transistor **FETb**.

[0110] Next, the configuration of the current mirror circuit **101a** will be described.

[0111] This current mirror circuit **101a** comprises a transistor pair composed of a first PNP transistor **Q4a** and a second PNP transistor **Q5a**, resistors **R4a**, **R5a**, **R6a**, **R7a**, and **R8a**, a capacitor **C3a**, and a Zener diode **Da**.

[0112] The bases of both the PNP transistors **Q4a** and **Q5a** are connected together and the capacitor **C3a** is connected between both emitters thereof to function as a low pass filter.

[0113] The resistors **R4a** and **R5a** are connected in series between the power supply terminal of the positive power supply voltage $+V_H$ and the ground terminal **GND**. The emitter of the PNP transistor **Q5a** is connected to the connection point of these resistors **R4a** and **R5a**. The resistors **R7a** and **R8a** are connected in series between the collector of the PNP transistor **Q5a** and the ground terminal **GND**. The excessive electric current detector **4a** is connected to the connection point of the resistors **R7a** and **R8a**.

[0114] The Zener diode **Da** is connected between the collector and the base of the PNP transistor **Q4a** to control the early effect and the collector of the transistor is connected to the ground terminal **GND** through the resistor **R6a** that functions as a reference current setting resistor. The emitter thereof is connected to the connection point between the resistor **RLa** and the transistor **FETa**.

[0115] In addition, the surface area (emitter size) of the emitter of the PNP transistor **Q5a** is smaller compared to the surface area (emitter size) of the emitter of the PNP transistor **Q4a**. As a result, compared to the voltage between the base and the emitter required to operate the PNP transistor **Q4a** in an ON state, the voltage between the base and the emitter required to operate the PNP transistor **Q5a** in an ON state is higher and the so-called deadband of the PNP transistor **Q5a** is larger. The voltage of this deadband is employed as a threshold value to detect an excessive electric current.

[0116] In the current mirror circuit **101a** with such a configuration described above, an electric current **Ira** that flows from the resistor **RLa** and then flows to the ground terminal **GND** through the PNP transistor **Q4a** and the resistor **R6a** serves as a reference electric current with a specified electric current value.

[0117] When there is no excessive electric current flowing in the resistor **RLa**, almost no electric current will flow in the PNP transistor **Q5a**, that has a deadband, while a **GND** voltage will be applied to the excessive electric current detector **4a** through the resistor **R8a** and this **GND** voltage will be detected by the excessive electric current detector **4a**. Because of this, the fact that no excessive electric current is flowing will be known.

[0118] In contrast, if an excessive electric current is flowing in the resistor **RLa**, the emitter voltage **VRLab** of the PNP transistor **Q4a** will fall (drop) in accordance with the

falling voltage $VRLa$ that occurs at the resistor RLa due to the excessive electric current and a fixed divided voltage that has undergone voltage division by the resistors $R4a$ and $R5a$ will always be applied to the emitter of the PNP transistor $Q5a$. Consequently, the emitter voltage of the PNP transistor $Q5a$ is constantly maintained. Because of this, if the voltage applied between the emitters of the PNP transistors $Q4a$ and $Q5a$ becomes larger in accordance with the falling voltage $VRLa$ along with the voltage applied between those emitters exceeding the deadband voltage (namely, the threshold value) $THDa$ of the PNP transistor $Q5a$, the PNP transistor $Q5a$ will be in an ON state and the excessive electric current detection current Ia , which shows that the excessive electric current is occurring, will flow out to the resistor $7a$.

[0119] As shown in FIG. 5(c), As a result of a falling voltage occurring at the resistor $R8a$ proportional to the excessive electric current detection current Ia , an excessive electric current detection voltage Sca , a voltage higher than the GND voltage, is applied to and detected by the excessive electric current detector $4a$, thereby making it possible to know that an excessive electric current is flowing.

[0120] In other words, the relationship of the following formulas (1) and (2) is established for the circuit configuration of the emitter side of the PNP transistors $Q4a$ and $Q5a$, where $|VRLa|$ is the absolute value of the falling voltage occurring at the resistor RLa when an excessive electric current is flowing, $Vbe(4a)$ is the voltage between the base and the emitter of the PNP transistor $Q4a$ through which the reference current Ira is always flowing, $Vbe(5a)$ is the voltage between the base and the emitter when the PNP transistor $Q5a$ is in an ON state, and $Vadev$ is the divided voltage (voltage at both ends of the resistor $R4a$) that has undergone voltage division by the resistors $R4a$ and $R5a$.

$$Vadev = \frac{R4a \cdot (+VH)}{R4a + R5a} \quad (1)$$

$$Vbe(5a) = |VRLa| - Vadev - Vbe(4a) \quad (2)$$

[0121] Since the divided voltage $Vadev$ is a fixed voltage, as a result of the flowing of an excessive electric current the PNP transistor $Q5a$ is turned ON if the absolute value of the falling voltage $|VRLa|$ is a voltage higher than the voltage of $(Vadev + Vbe(4a))$. The excessive electric current detection current Ia then flows out to the resistor $7a$, thereby making it possible to generate an excessive electric current detection voltage Sca and inform the electric current detector $4a$ that an excessive electric current has occurred as shown in FIG. 5(c).

[0122] It is also possible to adjust the detection sensitivity of the excessive electric current by adjusting the resistance ratio of the resistors $R4a$ and $R5a$ and the ratio of the emitter surface areas (emitter size ratio) of the PNP transistors $Q4a$ and $Q5a$.

[0123] The output impedance as seen at the collector of the PNP transistor $Q5a$ from the excessive electric current detector $4a$ is extremely high. Therefore, even if the power supply voltages $+VL$, $-VL$ of the excessive electric current detector $4a$ and the power supply voltages $+VH$, $-VLH$ of the class D amplifier 100 are different, it is possible to make

a process that performs level shifting of the detected excessive electric current to generate an excessive electric current detection signal Ia essentially unnecessary. It is also possible to reliably supply an excessive electric current detection current Ia , that shows the excessive electric current occurrence information, to the excessive electric current detector $4a$.

[0124] In the current mirror circuit $101a$ of this example, although an excessive electric current detection current Ia undergoes current-voltage conversion to an excessive electric current detection voltage by the resistors $R7a$ and $R8a$ and is then supplied to the excessive electric current detector $4a$, the resistors $R7a$ and $R8a$ can be omitted and an excessive electric current detection current Ia can be directly supplied to the excessive electric current detector $4a$.

[0125] In addition, although using a transistor pair composed of two PNP transistors $Q4a$ and $Q5a$ to form the current mirror circuit $101a$ was described, another transistor, such as a field-effect transistor, can also be used to form the current mirror circuit $101a$.

[0126] Next, the configuration of the current mirror circuit $101b$ will be described.

[0127] This current mirror circuit $101b$ also has a configuration identical to the current mirror circuit $101a$.

[0128] In other words, the current mirror circuit $101b$ comprises a transistor pair composed of a first NPN transistor $Q4b$ and a second NPN transistor $Q5b$, resistors $R4b$, $R5b$, $R6b$, $R7b$, and $R8b$, a capacitor $C3b$, and a Zener diode Db .

[0129] The bases of both the NPN transistors $Q4b$ and $Q5b$ are connected together and the capacitor $C3b$ is connected between both emitters thereof.

[0130] The resistors $R4b$ and $R5b$ are connected in series between the power supply terminal of the negative power supply voltage $-VH$ and the ground terminal GND. The emitter of the NPN transistor $Q5b$ is connected to the connection point of these resistors $R4b$ and $R5b$. The resistors $R7b$ and $R8b$ are connected in series between the collector of the NPN transistor $Q5b$ and the ground terminal GND. The excessive electric current detector $4b$ is connected to the connection point of the resistors $R7b$ and $R8b$.

[0131] The Zener diode Db is connected between the collector and the base of the NPN transistor $Q4b$ to control the early effect and the collector of the transistor is connected to the ground terminal GND through the resistor $R6b$ that functions as a reference current setting resistor. The emitter thereof is connected to the connection point between the resistor RLb and the transistor $FETb$.

[0132] In addition, the surface area (emitter size) of the emitter of the NPN transistor $Q5b$ is smaller compared to the surface area (emitter size) of the emitter of the NPN transistor $Q4b$. As a result, compared to the voltage between the base and the emitter required to operate the NPN transistor $Q4b$ in an ON state, the voltage between the base and the emitter required to operate the NPN transistor $Q5b$ in an ON state is higher and the so-called deadband of the NPN transistor $Q5a$ is larger. The voltage of this deadband is employed as a threshold value to detect an excessive electric current.

[0133] In the current mirror circuit **101b** with such a configuration described above, an electric current I_{rb} that flows from the ground terminal GND to the NPN transistor **Q4b** through the resistor **R6b** serves as a reference electric current with a specified electric current value.

[0134] When there is no excessive electric current flowing in the resistor **RLb**, almost no electric current will flow in the NPN transistor **Q5b**, that has a deadband, while a GND voltage will be applied to the excessive electric current detector **4b** through the resistor **R8b** and this GND voltage will be detected by the excessive electric current detector **4b**. Because of this, the fact that no excessive electric current is flowing will be known.

[0135] In contrast, if an excessive electric current is flowing in the resistor **RLb**, the emitter voltage V_{RLb} of the NPN transistor **Q4b** will rise in accordance with the falling voltage V_{RLb} that occurs at the resistor **RLb** due to the excessive electric current and a fixed divided voltage that has undergone voltage division by the resistors **R4b** and **R5b** will always be applied to the emitter of the NPN transistor **Q5b**. Consequently, the emitter voltage of the NPN transistor **Q5b** is constantly maintained. Because of this, if the voltage applied between the emitters of the NPN transistors **Q4b** and **Q5b** becomes larger in accordance with the falling voltage V_{RLb} along with the voltage applied between those emitters exceeding the deadband voltage (namely, the threshold value) THD_b of the NPN transistor **Q5b**, the NPN transistor **Q5b** will be in an ON state and the excessive electric current detection current I_b , which shows that the excessive electric current is occurring, will flow out to the resistor **7b**.

[0136] As shown in **FIG. 5(c)**, as a result of a falling voltage occurring at the resistor **R8b** proportional to the excessive electric current detection current I_b , an excessive electric current detection voltage S_{cb} , a voltage lower than the GND voltage, is applied to and detected by the excessive electric current detector **4b**, thereby making it possible to know that an excessive electric current is flowing.

[0137] In other words, the relationship of the following formulas (3) and (4) is established for the circuit configuration of the emitter side of the NPN transistors **Q4b** and **Q5b**, where $|V_{RLb}|$ is the absolute value of the falling voltage occurring at the resistor **RLb** when an excessive electric current is flowing, $V_{be}(4b)$ is the voltage between the base and the emitter of the NPN transistor **Q4b** through which the reference current I_{rb} is always flowing, $V_{be}(5b)$ is the voltage between the base and the emitter when the NPN transistor **Q5b** is in an ON state, and V_{bdev} is the divided voltage (voltage at both ends of the resistor **R4b**) that has undergone voltage division by the resistors **R4b** and **R5b**.

$$V_{bdev} = \frac{R_{4b} \cdot (-VH)}{R_{4b} + R_{5b}} \quad (3)$$

$$V_{be}(5b) = |V_{RLb}| - V_{bdev} - V_{be}(4b) \quad (4)$$

[0138] Since the divided voltage V_{bdev} is a fixed voltage, as a result of the flowing of an excessive electric current the NPN transistor **Q5b** is turned ON if the absolute value of the falling voltage $|V_{RLb}|$ is a voltage higher than the voltage of

$(V_{bdev} + V_{be}(4b))$. The excessive electric current detection current I_b then flows out to the resistor **7b**, thereby making it possible to generate an excessive electric current detection voltage S_{cb} and inform the electric current detector **4b** that an excessive electric current has occurred as shown in **FIG. 5(c)**.

[0139] It is also possible to adjust the detection sensitivity of the excessive electric current by adjusting the resistance ratio of the resistors **R4b** and **R5b** and the ratio of the emitter surface areas (emitter size ratio) of the NPN transistors **Q4b** and **Q5b**.

[0140] The output impedance as seen at the collector of the NPN transistor **Q5b** from the excessive electric current detector **4b** is extremely high. Therefore, even if the power supply voltages $+V_L$, $-V_L$ of the excessive electric current detector **4b** and the power supply voltages $+V_H$, $-V_LH$ of the class D amplifier **100** are different, it is possible to make a process that performs level shifting of the detected excessive electric current to generate an excessive electric current detection signal I_b essentially unnecessary. It is also possible to reliably supply an excessive electric current detection current I_b , that shows the excessive electric current occurrence information, to the excessive electric current detector **4b**.

[0141] In the current mirror circuit **101b** of this example, although an excessive electric current detection current I_b undergoes current-voltage conversion to an excessive electric current detection voltage by the resistors **R7b** and **R8b** and is then supplied to the excessive electric current detector **4b**, the resistors **R7b** and **R8b** can be omitted and an excessive electric current detection current I_b can be directly supplied to the excessive electric current detector **4b**.

[0142] In addition, although using a transistor pair composed of two NPN transistors **Q4b** and **Q5b** to form the current mirror circuit **101b** was described, another transistor, such as a field-effect transistor, can also be used to form the current mirror circuit **101b**.

[0143] According to the class D amplifier **100** as described above in the embodiment, the bias voltage level shifters **102a** and **102b** are provided. The bias voltage level shifter **102a** comprises: the NPN transistor **Q1a** that calculates a differential signal corresponding to the difference between the input modulated signal P_a and the positive power supply voltage $+V_L$; and the resistor **R2a** that generates the level-shifted signal P_{sa} by pulling up that differential signal towards the positive power supply voltage $+V_H$. The bias voltage level shifter **102b** comprises: the PNP transistor **Q1b** that calculates a differential signal corresponding to the difference between the input modulated signal P_b and the negative power supply voltage $-V_L$; and the resistor **R2b** that generates the level-shifted signal P_{sb} by pulling down that differential signal towards the negative power supply voltage $-V_H$. Consequently, drive signals P_{ga} and P_{gb} which each have a bias point suitable for the transistors **FETa** and **FETb** to operate in a push-pull manner can be supplied to these transistors **FETa** and **FETb**.

[0144] As a result, an output modulated signal P_{out} can be output from the transistors **FETa** and **FETb** without any waveform distortions, making it possible to perform efficient power amplification. Moreover, it is also possible to prevent a load that exceeds the allowable power loss from being

applied to the transistors FETa and FETb, thereby making it possible to prevent a state in which damage to the transistors occurs.

[0145] Because the current mirror circuits 101a and 101b, which serve as excessive electric current detection means, have a high output impedance for the excessive electric current detectors 4a, 4b, even if the power supply voltages +VL, -VL and the power supply voltages +VH, -VH are different, it is possible to make a process that performs level shifting the detected excessive electric current to excessive electric current detection currents Ia and Ib essentially unnecessary. As a result, any of the aspects of the invention can provide excessive electric current detection means that has a new configuration and does not require taking into consideration variations in level shifts due to Zener diodes which has been a problem with conventional technology. It is also possible to reliably supply excessive electric current detection currents Ia and Ib which indicate that excessive electric current is flowing in the transistors FETa and FETb to the excessive electric current detectors 4a, 4b.

[0146] While there has been described what are at present considered to be preferred embodiments of the present invention, it will be understood that various modifications may be made thereto, and it is intended that the appended claims cover all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A class D amplifier comprising:

a pair of switching elements composed of first and second switching elements which are complementally symmetrical with respect to a voltage of a power supply;

first bias voltage level shift means that generates a drive signal to be supplied to said first switching element by level-shifting a square-wave first input signal; and

second bias voltage level shift means that generates a drive signal to be supplied to said second switching element by level-shifting a square-wave second input signal,

said class D amplifier being provided for performing class D amplification by allowing said first and second switching elements to perform a push-pull operation based on the respective drive signals supplied thereto,

wherein said first bias voltage level shift means has first differential amplification means that calculates a differential signal between said first input signal and a predetermined voltage, and first bias means that generates a level-shifted drive signal to be supplied to said first switching element by pulling up said differential signal towards the power supply voltage of the first switching element,

wherein said second bias voltage level shift means has second differential amplification means that calculates a differential signal between said second input signal and a predetermined voltage, and second bias means that generates a level-shifted drive signal to be supplied to said second switching element by pulling down said differential signal towards the power supply voltage of the second switching element.

2. A class D amplifier having a pair of switching elements composed of first and second switching elements which are

complementally symmetrical with respect to a voltage of a power supply, said class D amplifier being provided for performing class D amplification by allowing said first and second switching elements to perform a push-pull operation based on the respective square-wave drive signals supplied thereto, p1 the class D amplifier comprising:

a first resistor connected between said first switching element and said power supply;

a second resistor connected between said second switching element and said power supply;

a first current mirror circuit that receives a falling voltage generated at both ends of said first resistor and generates an electric current corresponding to said falling voltage; and

a second current mirror circuit that receives a falling voltage generated at both ends of said second resistor and generates an electric current corresponding to said falling voltage,

wherein said respective currents output from said first and second current mirror circuits serve as an excessive electric current detection current that shows whether or not excessive electric currents flow in said first and second switching elements.

3. A class D amplifier comprising:

a pair of switching elements composed of first and second switching elements which are complementally symmetrical with respect to a voltage of a power supply;

first bias voltage level shift means that generates a drive signal to be supplied to said first switching element by level-shifting a square-wave first input signal; and

second bias voltage level shift means that generates a drive signal to be supplied to said second switching element by level-shifting a square-wave second input signal,

said class D amplifier being provided for performing class D amplification by allowing said first and second switching elements to perform a push-pull operation based on the respective drive signals supplied thereto,

wherein the class D amplifier further comprises:

a first resistor connected between said first switching element and said power supply;

a second resistor connected between said second switching element and said power supply;

a first current mirror circuit that receives a falling voltage generated at both ends of said first resistor and generates an electric current corresponding to said falling voltage; and

a second current mirror circuit that receives a falling voltage generated at both ends of said second resistor and generates an electric current corresponding to said falling voltage,

wherein said first bias voltage level shift means has first differential amplification means that calculates a differential signal between said first input signal and a predetermined voltage, and first bias means that generates a level-shifted drive signal to be supplied to said

first switching element by pulling up said differential signal towards the power supply voltage of the first switching element,

wherein said second bias voltage level shift means has second differential amplification means that calculates a differential signal between said second input signal

and a predetermined voltage, and second bias means that generates a level-shifted drive signal to be supplied to said second switching element by pulling down said differential signal towards the power supply voltage of the second switching element.

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